PHOTOMETRIC ANOMALIES IN OCEANUS PROCELLARUM.

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Introduction: Applying the phase-ratio technique to ground-based telescopic images of the Moon, we have found in Oceanus Procellarum several regions with anomalous phase functions of brightness (photometric anomalies) [1,2]. For these areas (see Fig. 1 and 2 in [1]), we do not observe a typical inverse correlation between albedo and steepness of the brightness phase curve. These regions demonstrate an anomalously large slope of the phase curves, which implies higher surface roughness. In particular, we have found the anomalous area in Mare Nubium with sharp edges, which is centered at 21.6S, 17.7W (~40 km in size, see Fig. 10 [1]). We have assumed these anomalies could result from bombardment of the lunar surface by a compact swarm of small impactors [1].

Later, using images acquired with the LROC WAC camera [3], we studied this area in more detail [4] and suggested an alternative interpretation of the anomaly. We suggested that the structure and composition feature can be related to a shallow flooding of an elevated highland area partially denuded by impacts that also produce stirring of the highland and mare material at the formation of the regolith layer [2]. Anomalous behavior of the phase function is explained by the difference of surface structure in the area and surrounding regions on the scales of less than 1 m that cannot be resolve by the camera LROC NAC [3]. This difference is due to the presence in the local regolith of excavated rocks and their fragments from the highland material background.

Developing a technique of seamless photometric mosaics on the base of LROC WAC data [4], we have built maps of the normal albedo A_0, the parameter of steepness η of phase curve $f(\alpha)=A_0\exp(-\eta\alpha^{0.6})$ [5], and TiO_2 abundance for the photometric anomaly in Mare Nubium (see Fig. 3 and 8 in [4]). The parameter η characterizes roughness of the lunar surface: the higher the value η, the rougher the surface. The resulting maps [4] reveal sharp edges of the anomaly, which do not correlate with topographic (elevation) maps [6]. We also noted that the composition map of TiO_2 shows lower (more typical for the highlands) abundance of TiO_2 in the anomaly in comparison with surrounding mare areas.

We here apply the approach proposed in [4] in order to characterize other photometric anomalies in Oceanus Procellarum. We consider three areas detected in [1], which are marked here as: Area 1 (Longitude: -35°...-31°, Latitude: -8°...-3.5°), Area 2 (Longitude: -38°...-33°, Latitude: -15°...-10°), and Area 3 (Longitude: -32°...-25°, Latitude: -17°...-10°).

Data and processing: For mapping A_0 and η, we have used source CDR WAC_COLOR images from the NASA archive http://wms.lroc.asu.edu/lroc/search in accordance with the following criteria: (1) the coordinate range is defined by studied scenes; (2) the incidence angle of the center of the image is $i \leq 70^{\circ}$; and (3) the spatial resolution of images is not lower than 100 m/pixel. As a result, there are several hundreds of images, depending on the scene sizes. For prognosis of TiO_2 abundance, Lucey's method [7] was used. We also have constructed a topography map with elevations using SLDEM2015 data [8] to compare with the distributions of photometric parameters and TiO_2 abundance.

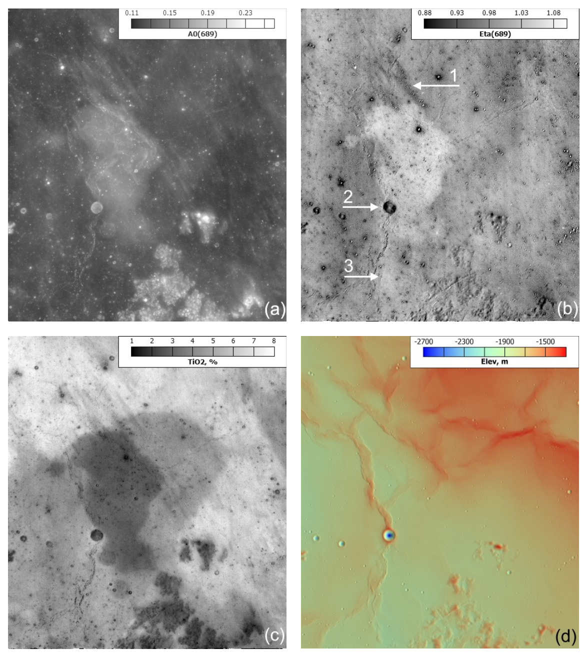

Figure 1. Area 1 (~120x140 km). (a): A_0(689 nm); (b): η(689 nm); (c): TiO_2 abundance; (d): topographic map.

Results and discussion: The outcome of our calculations is presented in Figs. 1-3. The numbering of anomalies corresponds to that in Fig. 1 from [1]. The new maps demonstrate rather sharp edges that do not correlate with topography. This is very similar to the anomaly in Mare Nubium. Moreover, in many cases the boundaries seen in albedo, roughness, and composition (TiO_2) are not coincident.

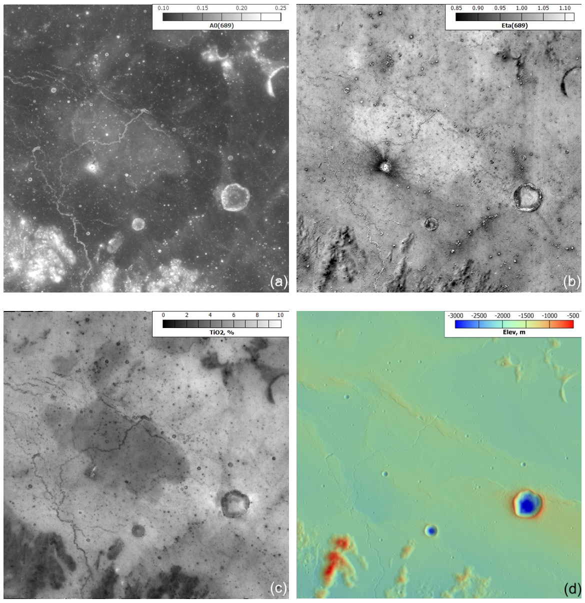

Figure 2. Area #2 (~150x150 km). (a): A_0(689 nm); (b): η(689 nm); (c): TiO_2 abundance; (d): topography.

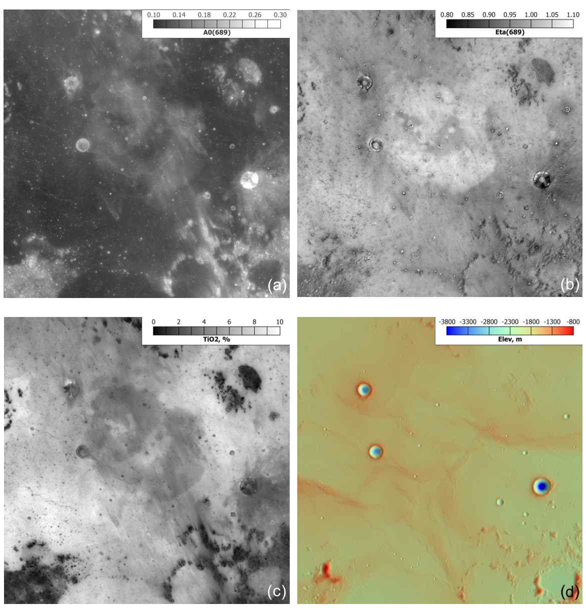

Figure 3. Area #3 (~210x210 km). (a): A_0(689 nm); (b): η(689 nm); (c): TiO_2 abundance; (d): topography.

The arrow 2 in Fig. 1 shows an example in which the photometric anomaly edge does not mimic albedo and composition (TiO_2) boundaries. The arrow 1 indicates a dark streak, which corresponds to a smoother surface than that in the anomaly area. It is interesting that the albedo of the streak is even lower than that of the anomaly. This streak is associated with a ray of the crater Tycho. The arrow 3 shows a south portion of the anomaly, which does not correlate with albedo and composition distributions at all. Similar features also can be found for other areas (see, e.g., Figs. 2 and 3) as well as for the photometric anomaly in Mare Nubium.

The anomalies shown in Fig. 1-3 can have originated by impacts that a shallow flooding of an elevated highland areas partially denuded [2]. In addition, we may suggest a hypothesis combining the swarm and denudation mechanisms. Recently, we have noted that some ejecta from the crater Tycho may cause lunar surface erosion and transportation of the eroded material [9]. The traces are seen near the Lubiniezky E crater as bright streaks. The highland material of the local topographic prominences is mobilized by Tycho's granolometrically fine ejecta and caused by its transportation along the ejecta pass to adjacent mare areas and subsequent deposition. We also may suppose that some Tycho ejecta are compact swarms of debris that loosen the lunar surface in areas of impact. In comparison with the primary impactor, the swarms have rather low velocity and a large portion of ejecta (highland) materials is saved on the surface and mixed with local regolith by later small impacts. Such a mixing may result in decrease of TiO_2 abundance. The unusual behavior of the phase function may be explained by the difference of surface structure in the anomalous area and surrounding regions on the scale of less than 1 m, which is imperceptible in the LROC NAC images.

Conclusions and future work: We can conclude that there are several photometrically anomalous areas in south part of Oceanus Procellarum. We suppose that they can be formed by opening up of the highland background in places of shallow mare flooding or by compact swarms of debris impactors ejected from the crater Tycho. Further studies of absolute ages of the formations would be important to understand their origin. We plan to use for such determinations the known technique of crater size-frequency distributions [10,11].

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